very rare

This brief memoir announces the discovery of self-induction.

On the Influence of a Spiral Conductor in increasing the Intensity of Electricity from a Galvanic Arrangement of a Single Pair.

by Joseph Henry.

(notes by S.P. Thompson)

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On the Influence of a Spiral Conductor in increasing the Intensity of Electricity from a Galvanic Arrangement of a Single Pair, &c. By Professor HENRY, *of New Jersey, U. S.*[*]

IN the American Journal of Science for July 1832, I announced a fact in Galvanism which I believe had never before been published. The same fact, however, appears to have been since observed by Mr. Faraday, and has lately been noticed by him in the November number of the London and Edinburgh Journal of Science for 1834.

The phænomenon as described by me is as follows: "When a small

[*] Read before the American Philosophical Society, Feb. 6th, 1835.—This has been annexed to the preceding papers as being referred to in them, and as a slight notice of it only has appeared in this country: see Phil. Mag. and Annals, vol. x. p. 314.

battery is moderately excited by diluted acid, and its poles, terminated by cups of mercury, are connected by a copper wire not more than a foot in length, no spark is perceived when the connexion is either formed or broken; but if a wire thirty or forty feet long be used instead of the short wire, though no spark will be perceptible when the connexion is made, yet when it is broken by drawing one end of the wire from its cup of mercury, a vivid spark is produced. If the action of the battery be very intense, a spark will be given by a short wire; in this case it is only necessary to wait a few minutes until the action partially subsides, or no more sparks are given; if the long wire be now substituted, a spark will again be obtained. The effect appears somewhat increased by coiling the wire into a helix; it seems also to depend in some measure on the length and thickness of the wire. I can account for these phænomena only by supposing the long wire to become charged with electricity, which, by its reaction on itself, projects a spark when the connexion is broken*."

The above was published immediately before my removal from Albany to Princeton; and new duties interrupted for a time the further prosecution of the subject. I have, however, been able during the past year to resume in part my investigations, and among others, have made a number of observations and experiments which develop some new circumstances in reference to this curious phænomenon.

These, though not as complete as I could wish, are now presented to the Society, with the belief that they will be interesting at this time on account of the recent publication of Mr. Faraday on the same subject.

The experiments are not given in the precise order in which they were first made, but in that which I deem best suited to render them easily understood; they have, however, been repeated for publication in almost the same order in which they are here given.

1. A galvanic battery, consisting of a single plate of zinc and copper, and exposing one and a half square feet of zinc surface, including both sides of the plate, was excited with diluted sulphuric acid, and then permitted to stand until the intensity of the action became nearly constant. The poles connected by a piece of copper bell-wire, of the ordinary size and five inches long, gave no spark when the contact was broken.

2. A long portion of wire, from the same piece with that used in the last experiment, was divided into equal lengths of fifteen feet, by making a loop at each division, which could be inserted into the cups of mercury on the poles of the battery. These loops being amalgamated, and dipped in succession into one of the cups while the first end of the wire

* Silliman's Journal, vol. xxii. page 408.

constantly remained in the other, the effect was noted. The first length, or fifteen feet, gave a very feeble spark, which was scarcely perceptible. The second, or thirty feet, produced a spark a little more intense, and the effect constantly increased with each additional length, until one hundred and twenty feet were used; beyond this there was no perceptible increase; and a wire of two hundred and forty feet gave a spark of rather less intensity. From other observations I infer, that the length necessary to produce a maximum result, varies with the intensity of the action of the battery, and also with its size.

3. With equal lengths of copper wire of unequal diameters, the effect was greater with the larger: this also appears to depend in some degree on the size of the battery.

4. A length of about forty feet of the wire used in experiments first and second, was covered with silk, and coiled into a cylindrical helix of about two inches in height and the same in diameter. This gave a more intense spark than the same wire when uncoiled.

5. A ribbon of sheet copper, nearly an inch wide and twenty-eight and a half feet long, was covered with silk, and rolled into a flat spiral similar to the form in which woollen binding is found in commerce. With this a vivid spark was produced, accompanied by a loud snap. The same ribbon uncoiled gave a feeble spark, similar in intensity to that produced by the wire in experiment third. When coiled again, the snap was produced as at first. This was repeated many times in succession, and always with the same result.

6. To test still further the influence of coiling, a second ribbon was procured precisely similar in length and in all other respects to the one used in the last experiment. The effect was noted with one of these coiled into a flat spiral and the other uncoiled, and again with the first uncoiled and the second coiled. When uncoiled, each gave a feeble spark of apparently equal intensity; when coiled, a loud snap. One of these ribbons was next doubled into two equal strands, and then rolled into a double spiral with the point of doubling at the centre. By this arrangement, the electricity, in passing through the spiral, would move in opposite directions in each contiguous spire, and it was supposed that in this case the opposite actions which might be produced would neutralize each other. The result was in accordance with the anticipation: the double spiral gave no spark whatever, while the other ribbon coiled into a single spiral produced as before a loud snap. Lest the effect might be due to some accidental touching of the different spires, the double spiral was covered with an additional coating of silk, and also the other ribbon was coiled in the same manner; the effect with both was the same.

7. In order to increase if possible the intensity of the spark while the battery remained the same, larger spirals were applied in succession.

The effect was increased, until one of ninety-six feet long, an inch and a half wide, and weighing fifteen pounds, was used. The snap from this was so loud that it could be distinctly heard in an adjoining room with the intervening door closed. Want of materials has prevented me from trying a larger spiral conductor than this; but it is probable that there is a length which, with a given quantity and intensity of galvanism, would produce a maximum effect. When the size of the battery is increased, a much greater effect is produced with the same spiral. Thus when the galvanic apparatus described in the first article is arranged as a calorimotor of eight pairs, the snap produced on breaking contact with the spiral last described resembled the discharge of a small Leyden jar highly charged.

8. A handle of thick copper was soldered on each end of the large spiral at right angles to the ribbon, similar to those attached to the wires in Pixii's magneto-electric machine for giving shocks. When one of these was grasped by each hand and the contact broken, a shock was received which was felt at the elbows; and this was repeated as often as the contact was broken. This shock is rather a singular phænomenon, since it appears to be produced by a lateral discharge, and it is therefore important to determine its direction in reference to the primary current.

9. A shock is also received when the copper of the battery is grasped by one hand, and the handle attached to the copper pole of the ribbon with the other. This may be called the direct shock, since it is produced by a part of the direct current. It is, however, far less intense than that produced by the lateral discharge.

10. When the poles were joined by two coils connected by a cup of mercury between them, a spark was produced by breaking the circuit at the middle point; and when a pair of platina wires was introduced into the circuit with the large coil and immersed in a solution of acid, decomposition took place in the liquid at each rupture of contact, as was shown by a bubble of gas given off at each wire. It must be recollected that the shocks and the decomposition here described were produced by the electricity from a single pair of plates.

11. The contact with the poles of the battery and the large spiral being broken in a vessel containing a mixture of hydrogen and atmospheric air, an explosion was produced.

I should also mention that the spark is generally attended with a deflagration of the mercury, and that when the end of the spiral is brought in contact with the edge of the copper cup or the plate of the battery, a vivid deflagration of the metal takes place. The sides of the cup sometimes give a spark when none can be drawn from the surface of the mercury. This circumstance requires to be guarded against when experimenting on the comparative intensities of sparks from different

arrangements. If the battery formerly described* be arranged as a calorimotor, and one end of a large spiral conductor be attached to one pole, and the other end drawn along the edge of the connector, a series of loud and rapid explosions is produced, accompanied by a brilliant deflagration of the metal; and this takes place when the excitement of the battery is too feeble to heat to redness a small platina wire.

12. A number of experiments were made to determine the effect of introducing a cylinder of soft iron into the axis of the flat spiral, in reference to the shock, the spark, &c.; but no difference could be observed with the large spiral conductor; the effect of the iron was merged in that of the spiral. When, however, one of the smaller ribbons was formed into a hollow cylindrical helix of about nine inches long, and a cylinder of soft iron an inch and a half in diameter was inserted, the spark appeared a little more intense than without the iron. The obliquity of the spires in this case was unfavourable to their mutual action, while the magnetism was greater than with the flat spiral, since the conductor closely surrounded the whole length of the cylinder.

I would infer, from these experiments, that some effects heretofore attributed to magneto-electric action are chiefly due to the reaction on each other of the several spires of the coil which surround the magnet.

13. One of the most singular results in this investigation was first obtained in operating with a large galvanic battery. The whole instrument was arranged as a calorimotor of eight pairs, and a large spiral conductor introduced into the circuit, while a piece of thick copper wire about five inches long united the poles. In this state an explosion or loud snap was produced, not only when the contact was broken at the spiral, but also when one end of the short wire at the other extremity of the apparatus was drawn from its cup. All the other short moveable connectors of the battery gave a similar result. When the spiral was removed from the circuit and a short wire substituted, no effect of the kind was produced. From this experiment it appears that the influence of the spiral is exerted through at least eight alternations of zinc, acid, and copper, and thus gives to a short wire at the other extremity of the circuit the power of producing a spark.

14. The influence of the coil was likewise manifest when the zinc and copper plates of a single pair were separated from each other to the distance of fourteen inches in a trough without partitions, filled with diluted acid. Although the electrical intensity in this case must have been very low, yet there was but little reduction in the apparent intensity of the spark.

* This battery consisted of eighty-eight elements or pairs, composed of plates of rolled zinc nearly one-eighth of an inch thick, nine inches wide, and twelve inches long, inserted into copper cases open at top and bottom.

15. The spiral conductor produces, however, little or no increase of effect when introduced into a galvanic circuit of considerable intensity. Thus when the large spiral used in experiment seventh, eighth, &c. was made to connect the poles of two Cruikshank's troughs, each containing fifty-six four-inch plates, no greater effect was perceived than with a short thick wire: in both cases in making the contact a feeble spark was given, attended with a slight deflagration of the mercury. The batteries at the same time were in sufficiently intense action to give a disagreeable shock. It is probable, however, that if the length of the coil were increased in some proportion to the increase of intensity, an increased effect would still be produced.

In operating with the apparatus described in the last experiment, a phænomenon was observed in reference to the action of the battery itself, which I do not recollect to have seen mentioned, although it is intimately connected with the facts of magneto-electricity, as well as with the subject of these investigations, viz. When the body is made to form a part of a galvanic circuit composed of a number of elements, a shock is, of course, felt at the moment of completing the circuit. If the battery be not very large, little or no effect will be perceived during the uninterrupted circulation of the galvanic current; but if the circuit be interrupted by breaking the contact at any point, a shock will be felt at the moment, nearly as intense as that given when the contact was first formed. The secondary shock is rendered more evident, when the battery is in feeble action, by placing in the mouth the end of one of the wires connected with the poles; a shock and flash of light will be perceived when the circuit is completed, and also the same when the contact is broken at any point; but nothing of the kind will be perceived in the intermediate time, although the circuit may continue uninterrupted for some minutes. This I consider an important fact in reference to the action of the voltaic current.

The phænomena described in this paper appear to be intimately connected with those of magneto-electricity, and this opinion I advanced with the announcement of the first fact of these researches in the American Journal of Science. They may, I conceive, be all referred to that species of dynamical *Induction* discovered by Mr. Faraday, which produces the following phænomenon, namely: when two wires, A and B, are placed side by side, but not in contact, and a voltaic current is passed through A, there is a current produced in B, but in an opposite direction. The current in B exists only for an instant, although the current in A may be indefinitely continued; but if the current in A be stopped, there is produced in B a second current, in an opposite direction however to the first current.

The above fundamental fact in magneto-electricity appears to me to be a direct consequence of the statical principles of "Electrical *Induction*"

as mathematically investigated by Cavendish, Poisson, and others. When the two wires A and B are in their natural state, an equilibrium is sustained by the attractions and repulsions of the two fluids in each wire; or, according to the theory of Franklin and Cavendish, by the attractions and repulsions of the one fluid, and the matter of the two wires. If a current of free electricity be passed through A, the natural equilibrium of B will be disturbed for an instant, in a similar manner to the disturbance of the equilibrium in an insulated conductor by the sudden addition of fluid to a contiguous conductor. On account of the repulsive action of the fluid, the current in B will have an opposite direction to that in A; and if the intensity of action remains constant, a new state of equilibrium will be assumed. The second state, however, of B may perhaps be regarded as one of tension; and as soon as the extra action ceases in it, the fluid in B will resume its natural state of distribution, and thus a returning current for an instant be produced.

The action of the spiral conductor in producing sparks is but another case of the same action; for since action and reaction are equal and in contrary directions, if a current established in A produces a current in an opposite direction in B, then a current transmitted through B should accelerate or increase the intensity of a current already existing in the same direction in A. In this way the current in the several successive spires of the coil may be conceived to accelerate, or to tend to accelerate each other; and when the contact is broken, the fluid of the first spire is projected from it with intensity by the repulsive action of the fluid in all the succeeding spires.

In the case of the double spiral conductor, in experiment sixth, the fluid is passing in an opposite direction; and according to the same views, a retardation or decrease of intensity should take place.

The phænomenon of the secondary shock with the battery appears to me to be a consequence of the law of Mr. Faraday. The parts of the human body contiguous to those through which the principal current is passing, may be considered as in the state of the second wire B; when the principal current ceases, a shock is produced by the returning current of the natural electricity of the body.

If this explanation be correct, the same principle will readily account for a curious phænomenon discovered several years since by Savary, but which I believe still remains an isolated fact. When a current is transmitted through a wire, and a number of small needles are placed transverse to it, but at different distances, the direction of the magnetic polarity of the needles varies with their distance from the conducting wire. The action is also periodical; diminishing as the distance increases, until it becomes zero; the polarity of the needles is then inverted, acquires a maximum, decreases to zero again, and then resumes

the first polarity; several alternations of this kind being observed*. Now this is precisely what would take place if we suppose that the principal current induces a secondary one in an opposite direction in the air surrounding the conductor, and this again another in an opposite direction at a great distance, and so on. The needles at different distances would be acted on by the different currents, and thus the phænomena described be produced.

The action of the spiral is also probably connected with the fact in common electricity called the lateral discharge: and likewise with an appearance discovered some years since by Nobili, of a vivid light, produced when a Leyden jar is discharged through a flat spiral.

The foregoing views are not presumed to be given as exhibiting the actual operation of nature in producing the phænomena described, but rather as the hypotheses which have served as the basis of my investigations, and which may further serve as formulæ from which to deduce new consequences to be established or disproved by experiment.

Many points of this subject are involved in an obscurity which requires more precise and extended investigation; we may, however, confidently anticipate much additional light from the promised publication of Mr. Faraday's late researches in this branch o science.

* Cumming's Demonferrande, p. 247; also Edinburgh Journal, October 1826.

NOTE.

[For an account of some recent investigations relative to the subject of the preceding Articles, the reader is referred to "An Inquiry into the Possibility and Advantage of the Application of Magnetism as a Moving Power: By the Rev. James William M'Gauley, in the Report of the Dublin Meeting of the British Association, 1835." See Phil. Mag. and Annals, vol. vii. p. 306. A further communication was made by the same gentleman at the Bristol Meeting, 1836. —Edit.]

Article XXVII.

A singular case of the Equilibrium of Incompressible Fluids; by M. Ostrogradsky.

(Read to the Academy of St. Petersburgh, February 19, 1836.)

From "*Mémoires de l'Académie Impériale des Sciences de St. Petersbourg,*" vol. iii. part 3.

In mechanics there is no other distinction made between different bodies or different systems of bodies, besides that which relates to their masses, their positions, and their possible displacements. These displacements, together with the mass or quantity of the inertia of each element being given, we have all that is requisite as well as indispensable to enable us to treat of the equilibrium and movement of any system.

That a system subjected to the action of any forces may remain in equilibrio, it is necessary that the forces should be incapable of producing any of those displacements of which the system is susceptible. Now, as the forces, though capable of producing all the displacements of which the whole momentum is positive, are yet unable to produce any of those which correspond to the zero or the negative momentum, the equilibrium of the system consequently requires that the whole momentum should be zero or negative for all the possible displacements. From this leading principle we may in the easiest and simplest manner derive the condition of equilibrium of a system without knowing anything more than the masses and the possible displacements. More particularly with respect to the equilibrium of liquids, we have, for instance, no need of the experimental principle known by the name of the principle of *equal pressure*, which, before the publication of the *Mécanique Analytique*, mathematicians were accustomed to consider as the basis of the theory of the equilibrium of fluids. It is sufficient to know how a liquid mass can be displaced, and this is the only datum by means of which, in the *Mécanique Analytique*, the equations relative to the equilibrium of liquids are deduced. But Lagrange having neglected the consideration of the displacements, accompanied by an augmentation of volume, though such displacements are evidently possible, was unable to deduce from his analysis the essential condition, that the quantity which represents the pressure must necessarily be positive. This condition being added, the theory of Lagrange will be the most satisfactory of all those in which the liquids are considered as continuous masses; and if there is anything further to be remarked, it is that the incompressibility of the differential parallelopipeds is there taken as the condition of the incompressibility of the fluid, though it should be